Experimental investigation of cylindrical rotating detonation engine with film cooling

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Abstract

We conduct an experimental investigation on the integration of film cooling for thermal protection in a 72-mm cylindrical rotating detonation engine (RDE). The cooling scheme employs the injection of cooling air through a series of cat-ear-shaped film cooling holes densely distributed along the outer wall of the cylindrical combustor. Our findings reveal successful initiation of the RDE and sustained propagation of the rotating detonation wave (RDW) when film cooling is activated.

1、 Introduction

The rotating detonation engine (RDE) is a revolutionary technology that has gained global attention in the field of aerospace propulsion due to the characteristics of pressure gain combustion (PGC), fast heat release and higher thermodynamic cycle efficiency compared with that of traditional deflagration-based power systems. However, as highlighted by Roy et al. [1], the advancement of detonation-based power systems encounters a significant obstacle in the need for effective thermal protection to overcome the high-frequency thermal load caused by the detonation wave. In our previous studies [2, 3], the feasibility of film cooling for the thermal protection of RDEs has been explored by numerical simulations. In the current research, an experimental investigation is conducted to verify the ignition and operation of an RDE integrated with film cooling.

2、 Experimental setup

The rotating detonation combustor (RDC) is a cylindrical design with an outer diameter of d =72 mm and a length of L =77.5 mm, as shown in Fig. 1. Hydrogen and air are injected into the RDC through separate injectors. In total, 390 cat-ear-shaped film cooling holes are densely distributed and manufactured on the outer wall surface (thickness δ =1.5 mm) by femtosecond laser processing technology.

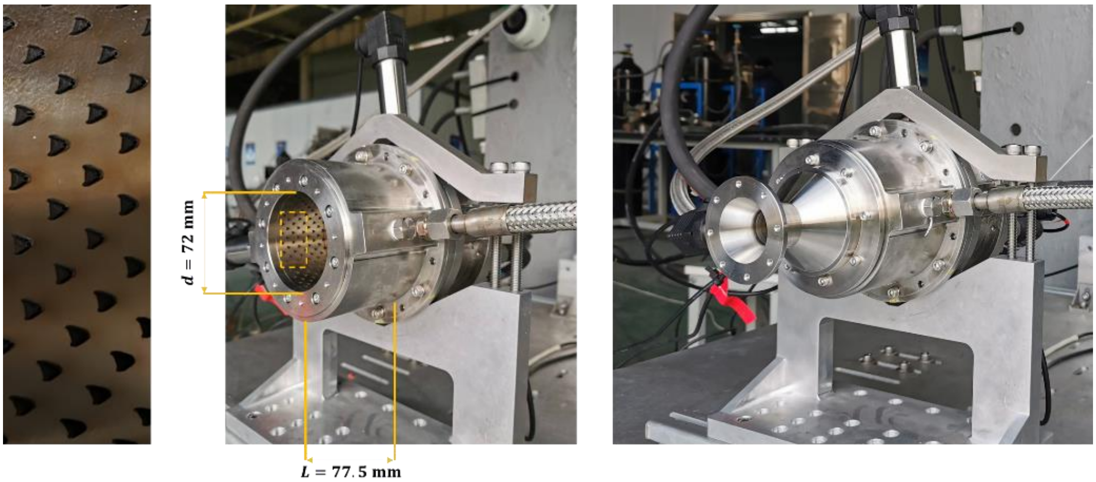

Figure 1: Cylindrical RDE with film cooling.

3、 Results and Discussion

The hydrogen-fueled RDE is ignited by an automobile spark plug. The working conditions of two test shots are summarized in Table 1. In shot No. 1, the duration is set to 0.5 s after ignition and injection of cooling air and high-frequency pressure transducer is mounted. In shot No. 2, the duration is increased to 2 s. The exhaust plumes of the two shots are shown in Fig. 2.

Table 1 Working conditions

	Hydrogen [g/s]	Air (propellent) [g/s]	Air (cooling) [g/s]
Shot 1	8.7	300	100
Shot 2	8.7	300	120

In shot No. 1, the dominant frequency of the RDW obtained by a fast Fourier transition (FFT) analysis is 10 kHz, indicating the propagation of the RDW. The existence of the RDW can also be confirmed by the shock diamond in the exhaust plume. In shot No. 2, the RDE operates for 2 s with the mass flow rate of cooling air increasing to about 120 g/s. The exhaust plume of Fig. 2(b) is found to be similar to that of Fig. 2(a) except for different daylight exposures, suggesting supersonic jets in both working conditions.

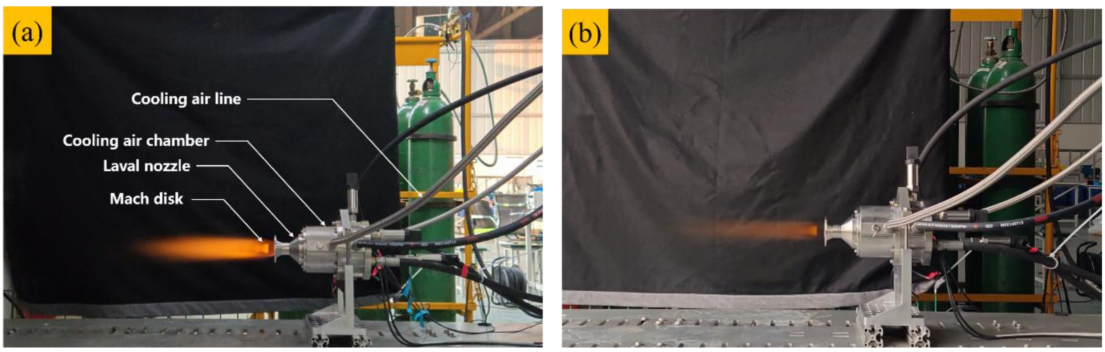

Figure 2: Exhaust plumes: (a) shot No. 1 (b) shot No. 2.

Figure 3 shows the inner surface of the outer wall after the long-time shot. The trace of cooling air can be clearly reflected by the temperature difference of burn marks; near the film cooling holes,

the wall surface is better protected by the cooling air. Additionally, the cooling jet is found to swing laterally under the influence of the RDW. These experimental findings align well with our previous numerical study, and a comparison is presented.

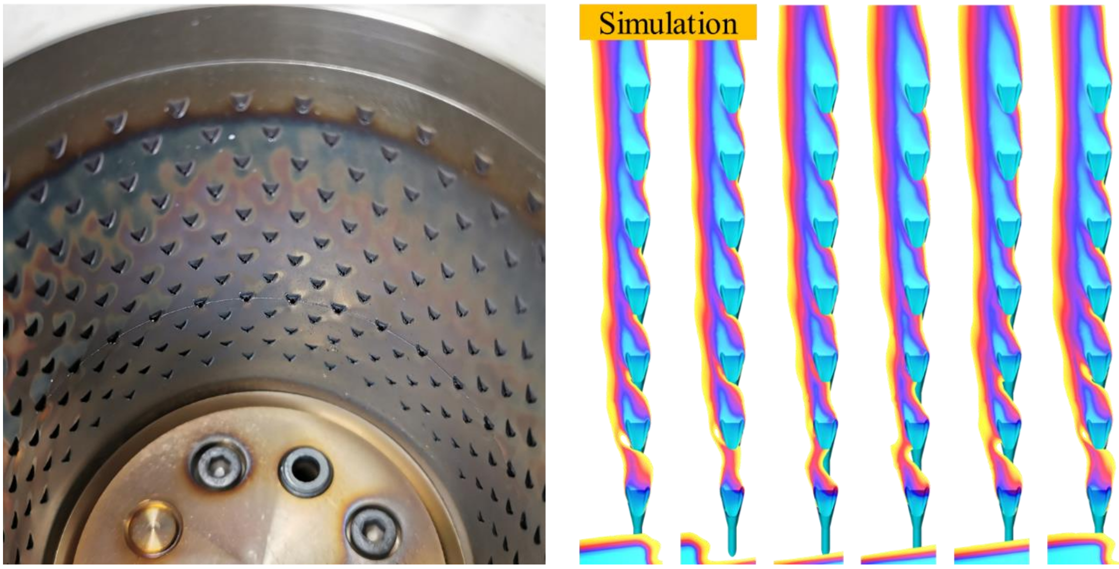

Figure 3: Outer wall surface condition after ignition of RDE and passage of RDW. Simulation result from Yu et al. [2].

4、 Conclusions

In conclusion, our experimental investigation into the integration of film cooling for thermal protection in a cylindrical RDE has yielded promising results. The successful initiation and sustained propagation of the RDW during the activation of film cooling are reported. The experimental findings also verify the characteristics of the cooling jet in the RDW flow field revealed by numerical simulations.

References

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